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ABSTRACT

A study of consonant-vowel linkages focused on the nature of the vowel boundaries with onset and codas. Subjects judged the status of various word pairs as possible exemplars of a particular manipulation they had been taught to listen for in model nonsense words. The models were of three distinct tasks: (1) a nucleus substitution task, to replace the vowel sound with /I/; (2) an onset deletion task, to delete everything before the vowel; and (3) a coda substitution task, to replace everything after the vowel sound with /ps/. Analysis of the results was performed from the perspective of classical signal deletion theory. Overall, the results showed a coherent pattern corresponding well to other evidence of real-time phonological organization. Pre-vocalically, all resonants are effectively separable from following vowels, though glides are less so than others. There was also some evidence that pre-vocalic liquids /l/ and /r/ are more vowel-sticky than nasals. Post-vocalically, glides are absolutely vowel-sticky, with listeners finding it almost impossible to separate such glides from vowels. Post-vocalic /r/ was found to be somewhat less tightly bound to the vowel than glides, and /l/ even less so. Only nasals showed unequivocal consonant-stickiness in all tasks. (MSE)

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On the Structure of the Vowel Nucleus: Experimental Evidence....

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1. INTRODUCTION

Following up on the ground-breaking research by Treiman, Dow undertook an extensive experimental investigation of the psychological reality of sub- or intra-syllabic units, in order to explore the suggestion that there may be psychologically significant units that are intermediate in scope between the syllable and individual phonemes. The main technique used in all of these studies might aptly be described as 'experimental word games', in which subjects are required to manipulate various parts of words in accord with some model or set of instructions. Treiman (1983), for example, taught subjects a word game in which the onset of one monosyllable was blended with the rime of another, as well as other games in which the onsets or rimes were broken up [SEE HANDOUT 1]. She found that the game that kept both onset and rime intact was learned with fewer errors than were the other three games. This provided some evidence that onsets and rimes function as cohesive units in the real-time phonological organization of English.

Dow extended this work in her 1987 dissertation. Her main experimental procedure, called a substitution-by-analogy task, involved the replacement of some portion of a monosyllabic string on the basis of a two-example model (e.g., cling-string and beam-stream, which both involve the replacement of their onset sequences by the new onset /str-/). A few examples are given [SEE HANDOUT 2] for each of the six units tested.

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The results for forty adult listeners were clear and consistent throughout, on three different response measures: ACCURACY, RESPONSE LATENCY, and ERROR TYPE [SEE HANDOUT 3]. These results indicate that onsets and rimes are the most easily manipulable of the six proposed units, and that heads and margins are by far the most difficult, with the nuclei and codas falling in between. For English, therefore, these findings lend some support to the popular right-branching model of syllable structure, which links the nucleus with the coda into a rime constituent, as opposed to a left-branching model that links the nucleus more closely with the onset into what is called here a head (analogous to what Vennemann 1987 calls the 'body'). The integrity of the onset and coda was also supported by another string-manipulation study carried out by Dow (1987), in which high school subjects were required to delete parts of syllables. These subjects were considerably more successful in deleting whole onsets and codas (about 90% correct on both tasks) than in deleting incomplete units (63% correct).

A question that was not systematically explored by Dow, however, was the nature of the boundaries between these kinds of units. Are the boundaries sharp (as implied by hierarchical theories, such as the right-branching model just referred to), or are such units more properly viewed as a consequence of 'affinity bonds' between phonemes that can vary in strength, depending on their position in the syllable (as suggested by Vennemann 1987, for example). And, if the latter, does the strength of the bondings to the nucleus, in particular, vary as a function of the putative 'sonority hierarchy' proposed by Hooper (1976) and others?

Treiman (1984) investigated this matter by means of another 'blending task', involving VCC syllables. She found that subjects tended to keep the liquids /l,r/ together with the vowel, but to separate obstruents off as part

of the consonantal coda, while nasals were in an ambiguous, neutral position. The present experiment was conducted in order to explore the question of consonant-vowel linkages in a more thorough and systematic way, as well as to extend it to the study of pre- as well as post-vocalic consonants.

2. PROCEDURE

In order to collect large amounts of data from groups of subjects, a new experimental technique was employed. Rather than actually performing each manipulation, listeners simply judged the status of various word-pairs as possible exemplars of the particular manipulation they had been taught to listen for. In brief, the experimental procedure was as follows:

(1) Subjects were first given several nonsense word-pairs as models of one of the following three tasks:

(a) The Nucleus Substitution Task, which was effectively to REPLACE THE VOWEL SOUND BY /ɪ/.

(b) The Onset Deletion Task, which was effectively to DELETE EVERYTHING BEFORE THE VOWEL SOUND.

(c) The Coda Substitution Task, which was effectively to REPLACE EVERYTHING AFTER THE VOWEL SOUND BY /ps/.

Sample training sets for each of these tasks are presented on the handout [SEE HANDOUT 4]. Note that all of the training items contain only obstruents in the critical pre- or post-vocalic positions.

(2) Subjects were then given a series of practice trials, in which they were asked to judge whether a new word-pair was or was not an example of the substitution pattern that they had been taught. (These practice items were like the training items in containing only obstruents in the critical positions.)

(3) Subjects were then given the test stimuli, with a rest period about halfway through the list on each task. In order to remind subjects of the

nature of the task, as well as provide an experimental control, every eighth item on each test was a reinforcement item based on the original training and practice lists.

The test items were constructed to provide examples of glides (/w, y/), liquids (/l, r/) and nasals in the critical pre- and post-vocalic environments [SEE HANDOUT 5].

3. RESULTS

We will present our analysis from the point of view of classical signal detection theory. Consider first the Onset Task of Table 1 [SEE HANDOUT 6], where the target manipulation was to "delete everything before the vowel sound". In this case, a correct detection or "HIT" consists of saying YES to a trial where the vowel is separated from the adjacent resonant. Thus in the first column of Table 1, a "HIT" corresponds to a YES response to the pair /snæks/-/æks/. This corresponds to the correct manipulation from the point of view of a simple linear theory of the syllable.

On the other hand, a "FALSE ALARM" consists of saying YES to a trial where, in effect, the resonant has "stuck to the vowel". This would correspond to saying YES to a /snæks/-/næks/ trial. (Note that HIT and FALSE ALARM rates are based on different, but related word pairs and hence the HIT and FALSE ALARM rates for a given category need not add up to 100%.)

Following signal detection procedures, d', a measure of detectability of the "nominally correct" pattern, can be calculated as a function of the HIT and FALSE ALARM rates. A large positive d' results from a high HIT rate, coupled with a low FALSE ALARM rate. Roughly speaking, d' can here be viewed as an index of "Consonant-stickiness". A large positive value of d' indicates that the resonsant has "stuck to the neighboring obstruent". On the other hand, large negative values of d' correspond to a strong tendency

toward Vowel-stickiness.

We see from Table 1 that for all of the manner classes, d' reaches significant positive values, i.e., the HIT rate is significantly greater than the FALSE ALARM rate. This means that, in absolute terms, all the pre-vocalic resonants are Consonant-sticky rather than Vowel-sticky. But there is also some indication that it is more difficult for glides to stick to a preceding consonant than for a nasal or liquid to do so. There is a much larger FALSE ALARM rate in the cases of glides. More than half the time, listeners said "YES" to examples like /pyuwn/-/yuwn/, where the glide has stuck to the vowel.

We can test for relative differences in Consonant-stickiness by paired difference t-tests of d' for the different manner classes. The results are indicated below Table 1. Results show that nasals and liquids are about equal in Consonant-stickiness, while glides are significantly less Consonant-sticky and more Vowel-sticky.

Table 2 [HANDOUT] shows a similar analysis for the Nucleus Substitution Task, where the target manipulation was to "replace the vowel sound". In this case, a HIT is defined as a YES response to trials where only the vowel is replaced and the resonant remains stuck to an initial obstruent. An example of a HIT is YES as a response to a pair like /flækt/-/flɪkt/. On the other hand, a FALSE ALARM is defined as a YES response to a case where the original vowel and the preceding resonant have <u>both</u> been replaced by /ɪ/; thus a YES response to /flækt/-/fɪkt/ is a FALSE ALARM.

The results of this task are largely compatible with the Onset Deletion Task. The only new wrinkle is that the liquids /l/ and /r/ now show intermediate results. They have a relatively greater amount of Vowel-stickiness than nasals, but less than the glides. This parallels Treiman's

findings for post-vocalic resonants and, overall, lends support to the 'sonority hierarchy'.

Interestingly, the Vowel-stickiness of the glides also appears to agree with previous findings related to the /y/+/u/ sequence. For example, Dow (1981) found that words like /kyu/ and /fyu/ were judged to contain two rather than three speech sounds, as though the sequence /yu/ was being counted as a single unit. In addition, the speech error data of Shattuck-Hufnagel (1986) show a marked propensity for a /y/+/u/ sequence to move together as a unit.

Let us now consider the data for post-vocalic resonants. Consider first the Nucleus Substitution Task of Table 3 [HANDOUT], where the target manipulation was to "replace the vowel sound by /ɪ/". In this case, a HIT is defined as a YES response to trials where only the vowel is replaced and the resonant is left stuck to the final obstruent; thus a YES response to /stɛln/-/stɪln/ constitutes a HIT. On the other hand, a FALSE ALARM is a YES response to a case where the original vowel and the following resonant have <u>both</u> been replaced by /ɪ/, as in the /stɛln/-/stɪn/ example.

These results indicate that for post-vocalic resonants the order of increasing Vowel-stickiness is nasal, /l/, /r/, and glide. Note that for both listener groups, glides are <u>absolutely</u> Vowel-sticky, as they show significantly <u>negative</u> d' values. FALSE ALARM rates are absolutely higher than HIT rates.

Finally, consider the data for the Coda Task in Table 4 [HANDOUT], where the target manipulation was to "replace everything following the vowel sound with /ps/". Here we define a HIT as a YES response to a trial like /zɛlf/-/zɛps/, where the post-vocalic /l/ has separated from the vowel and has been replaced along with the /f/. By the same token, a FALSE ALARM

corresponds to a YES response to a pair like /zɛlf/-/zɛlps/, in which the resonant has stuck to the vowel.

These results show a very strong tendency for resonants to stick to the vowel -- stronger than for any other task. In fact, only nasals are positively Consonant-sticky in the absolute sense and, even here, the FALSE ALARM rate is over 50%; /l/ is essentially neutral, with both FALSE ALARMs and HITs on the order of 65%. Now /r/ joins the glides as absolutely Vowel-sticky, showing significantly negative d' values. The overall pattern in increasing order of Vowel-stickiness is again nasal, /l/, /r/, and glide.

To summarize, our results show a coherent pattern that corresponds quite well with other evidence of real-time phonological organization. Pre-vocalically, all resonants are relatively separable from following vowels, though glides (especially /y/) are less so than the others. There is also some evidence that the pre-vocalic liquids /l/ and /r/ are more Vowel-sticky than nasals.

Post-vocalically, glides are absolutely Vowel-sticky, as listeners find it almost impossible to separate out such glides from vowels. This is in accord with Dow's prior segment-count studies (1981) and with speech error data from Shattuck-Hufnagel (1986), which show that diphthongs almost always move together as single units. This weight of evidence virtually demands a monophonemic analysis of diphthongs, in which the post-vocalic glides behave more like "features" than independent segments.

Post-vocalic /r/ is somewhat less tightly bound to the vowel than the glides, and /l/ even less so. Only nasals show unequivocal Consonant-stickiness in all tasks.

On the whole, because of the "gradualness" of our results, we believe that they are more in line with a scalar "bonding" model of English syllable

structure than with a strictly hierarchical model. However, there are a number of subtler issues that our stimuli were not designed specifically to test that could have a bearing on this issue. Notable among these are some of the "collocational" restrictions of Selkirk (1982) that may affect the constituency of resonants within the rime. Although a finer partitioning of the data reported here does not provide sufficient evidence to decide these issues at this time, we believe that available experimental techniques can be readily modified to that end. We hope to report the results of just such tests to a future meeting of the society.

On the Structure of the Vowel Nucleus: Experimental Evidence

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1. Treiman (1983): /fl-irz/ + /gr-uns/ = /fl-uns/
(cf. /f-runs/, /fli-ns/, and /flir-s/)

2. Dow (1987):

Substitution	Examples	Stimulus:(target)	Type
(a) Replace onset by /str-/	cling-string beam-stream	duck:(struck)	Match
(b) Replace nucleus by /ay/	glade-glide dove-dive	says:(size)	Mismatch
(c) Replace coda by /-nts/	past-pants blimp-blintz	love:(/lʌnts/)	Nonsense
(d) Replace rime by /-ʌnt/	freak-front stealth-stunt	pest:(punt)	Match
(e) Replace head by /kræ-/	floss-crass drift-craft	chic:(crack)	Mismatch
(f) Replace margins by /b-...-t/	strife-bite mouse-bout	crook:(/bʊt/)	Nonsense

3. Results of substitution-by-analogy task (N=40 adults)

Accuracy (Proportion Correct)		Reaction Time (Seconds)		Preferred Errors (Mean Number)	
Rhyme	.77	Rhyme	1.8	Onset	13.6
Onset	.65	Onset	2.1	Rhyme	10.9
Nucleus	.59	Nucleus	2.6	Coda	5.7
Coda	.47	Coda	3.1	Nucleus	4.1
Margins	.26	Margins	4.1	Margins	3.3
Head	.20	Head	4.6	Other	3.1
				Head	1.3

4. Partial Training Sets

Nucleus Task	Onset Task	Coda Task
/tæǰ/-/tɪǰ/	/spiysk/-/iysk/	/skæ/-/skæps/
/stɔv/-/stɪv/	/sɔyt/-/ɔyt/	/vɪk/-/vɪps/
/vʌkst/-/vɪkst/	/pɛnt/-/ɛnt/	/smʊs/-/smʊps/
/spɛdz/-/spɪdz/	/skowv/-/owv/	/fʌsk/-/fʌps/
/bʊpst/-/bɪpst/	/fʌnǰ/-/ʌnǰ/	/twɪš/-/twɪps/

5. Sample Test Items

Nucleus Task	Onset Task	Coda Task
1a. /tɐyv/-/tɪv/	6a. /syuwg/-/uwg/	11a. /snɔy/-/snɔps/
b. /tɐyv/-/tiyv/	b. /syuwg/-/yuwg/	b. /snɔy/-/snɔyps/
2a. /kwɛft/-/kɪft/	7a. /kwiyf/-/iyf/	12a. /byowst/-/byɔps/
b. /kwɛft/-/kwɪft/	b. /kwiyf/-/wiyf/	b. /byowst/-/byowps/
3a. /pɔlv/-/pɪv/	8a. /pleyk/-/eyk/	13a. /rɛlst/-/rɛps/
b. /pɔlv/-/pɪlv/	b. /pleyk/-/leyk/	b. /rɛlst/-/rɛlps/
4a. /drʌž/-/dɪž/	9a. /krɛmp/-/ɛmp/	14a. /bɔrk/-/bɔps/
b. /drʌž/-/drɪž/	b. /krɛmp/-/rɛmp/	b. /bɔrk/-/bɔrps/
5a. /spænǰ/-/spɪǰ/	10a. /snɪlb/-/ɪlb/	15a. /fʌmpt/-/fʌps/
b. /spænǰ/-/spɪnǰ/	b. /snɪlb/-/nɪlb/	b. /fʌmpt/-/fʌmps/

6. "Correct Pattern" = manipulation that "follows the instructions" according to a simple linear theory of syllable structure.

HIT = YES to a pattern where resonant sticks to adjacent obstruent.
FALSE ALARM (F.A.) = YES when resonant sticks to vowel.

Consonant-stickiness: high HIT rate, low FALSE ALARM rate, large positive d'

Vowel-stickiness: low HIT rate, high FALSE ALARM rate, large negative d'

Table 1. Pre-vocalic resonants in "onset deletion task". N of listeners=58.

Example	Type	Nasal	/l/	/r/	Glide
/snæks/-/æks/	HIT	98.3	99.3	99.0	88.1
/snæks/-/næks/	F.A.	3.0	3.2	1.2	56.9
C-stickiness	d'	8.69**	8.66**	8.77**	2.86**

Relative C-stickiness: **N, L, R >> G**

Two tailed t-tests of d' against 0: (*) $p<.05$ *$p<.01$ **$p<.005$
Paired difference t-test: x (>) y : $p<.05$ x > y : $p<.01$ x >> y : $p<.005$

Table 2. Pre-vocalic resonants in "nucleus substitution task". N=58.

Example	Type	Nasal	/l/	/r/	Glide
/flækt/-/flɪkt/	HIT	94.8	95.3	90.0	84.1
/flækt/-/fɪkt/	F.A.	8.6	23.3	20.7	46.8
C-stickiness	d'	7.93**	6.26**	5.87**	2.51**

Relative C-stickiness: **N >> L, R >> G**

Table 3. Post-vocalic resonants in "nucleus substitution task". N=41.

Example	Type	Nasal	/l/	/r/	Glide
/stɛln/-/stɪln/	HIT	84.4	75.0	54.1	30.0
/stɛln/-/stɪn/	F.A.	23.0	28.4	32.1	80.5
C-stickiness	d'	4.36**	2.92**	1.61**	-4.43**

Relative C-stickiness: **N >> L (>) R >> G**

Table 4. Post-vocalic resonants in "coda substitution task". N=42.

Example	Type	Nasal	/l/	/r/	Glide
/zɛlf/-/zɛps/	HIT	72.6	63.7	39.3	42.9
/zɛlf/-/zɛlps/	F.A.	53.6	67.3	70.1	90.5
C-stickiness	d'	1.63*	-0.14	-2.57**	-4.26**

Relative C-stickiness: **N >> L >> R >> G**

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ABSTRACT

This paper represents a continuation of our experimental investigation of the internal structure of English syllables, as reflected in the performance of native speakers on a variety of psycholinguistic tasks. While prior work has shown that significant units (such as the onset, rhyme, nucleus and coda) do exist between the level of the syllable and the level of the individual segment (or phoneme), the nature of the boundaries between such units was not clear. To explore this question, a new kind of pattern-recognition task was devised in which subjects were trained on one of the following three unit-manipulation patterns: (1) replace the vowel nucleus by /ɪ/ (e.g., /stɔv/ - /stɪv/), (2) delete the onset (e.g., /skowv/ - /owv/), or (3) replace the coda by /ps/ (e.g., /vɪk/ - /vɪps/), all with obstruents in the critical pre- or post-vocalic positions. Subjects were then asked to judge whether new nonce-word pairs did or did not illustrate the pattern in question, this time with resonant consonants appearing in the critical positions (e.g., /spænǰ/ - /spɪǰ/ and /spænǰ/ - /spɪnǰ/ for the nucleus substitution task).

On the basis of a classical signal detection analysis, the results of all three studies show an overall tendency , in both pre- and post-vocalic position, for resonant consonants to bond with the vowel in accord with the predictions of the 'sonority hierarchy': glides (most vowel-sticky) > /r/ > /l/ > nasals (most consonant-sticky). The 'gradualness' of these results also suggests that a scalar 'bonding' model is to be preferred over a strictly hierarchical one for English.